CMC Technology Advancements for Gas Turbine Engine Applications

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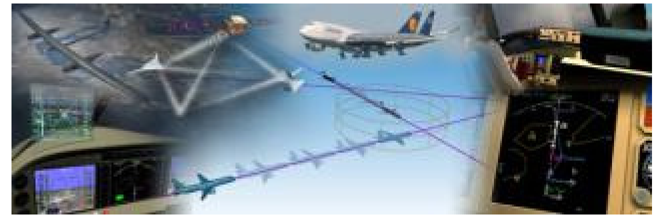
NASA Aeronautics Programs

Fundamental Aeronautics Program

Conduct fundamental research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

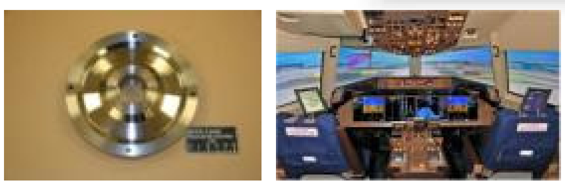
Integrated Systems Research Program

Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment



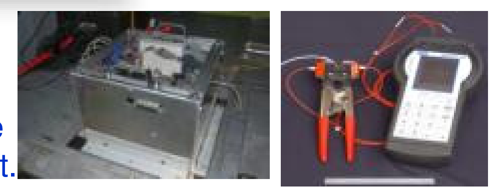
Airspace Systems Program

Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.



Aviation Safety Program

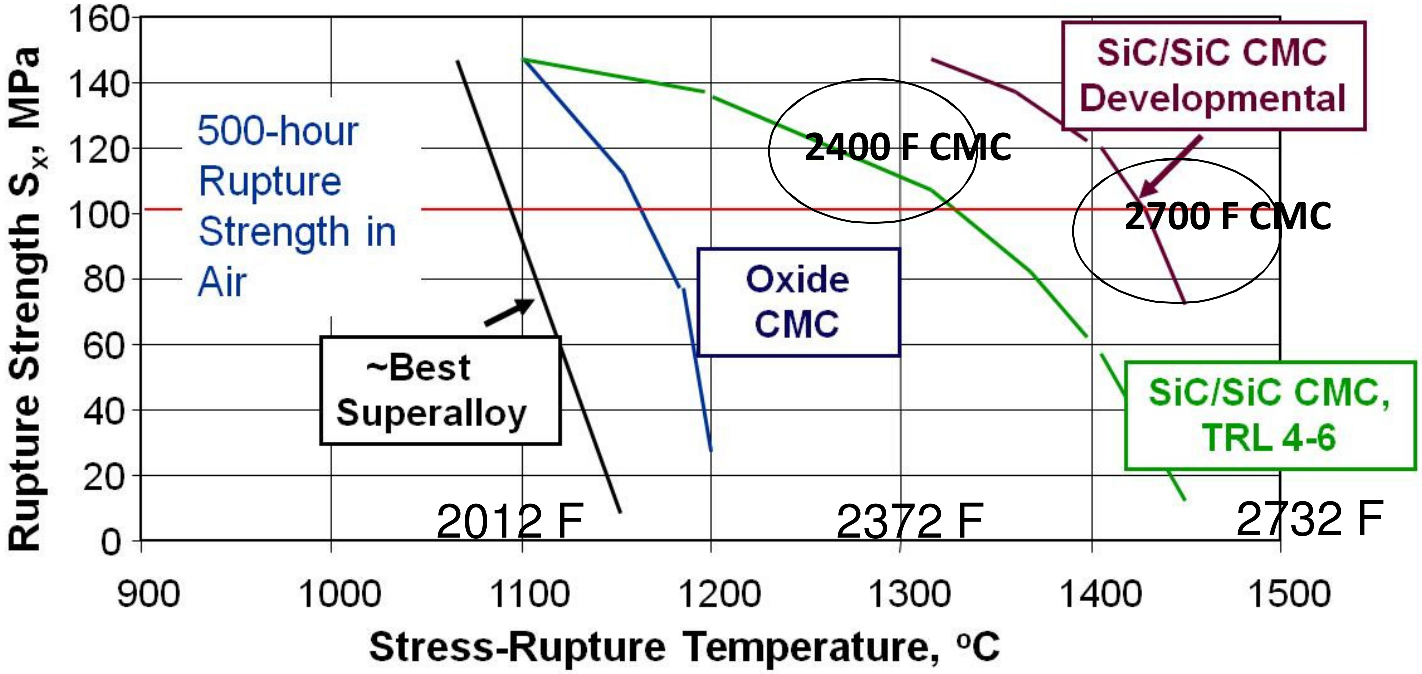
Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.



Aeronautics Test Program

Preserve and promote the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.

Turbine engine applications for ceramic composites



SiC/SiC CMC offers at least 400°F advantage over superalloys at 1/3 density

Summary of Fuel Burn Reduction

(2700 ºF CMC Materials)

CMC "Technology"	SFC Reduction	Engine Wt Reduction	Fuel Burn Reduction
HPT Vanes	-0.5%	-0.45%	-0.95%
HPT Blades*	-1.8%	-0.8%	-3.1%
LPT Vanes/Blades*	0	-3.6%	-0.7%
Burner ΔP (5% to 3%)	-0.75%	0	-1.25%
Overall Reduction	-3.0%	-4.85%	6.0%

NASA's CMC research is focused on technology advancements needed for turbine applications

- SiC/SiC composite with 20 ksi strength for 300 hours at 2700°F
- Advanced fiber with increased creep resistance and sufficient high temperature strength
- Advanced matrix with high matrix cracking stress and thermal conductivity
- Durable 2700°F Environmental Barrier Coating
- Joining & Integration
- Life Prediction

Fabrication Process for 2700°F Fiber

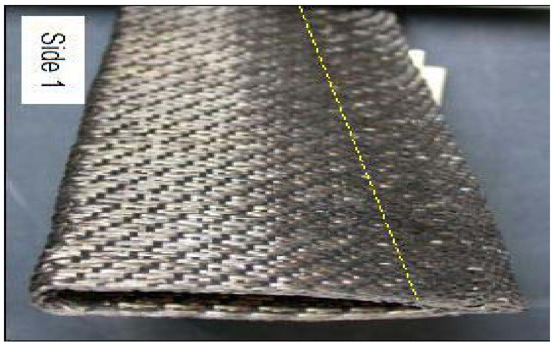
Boron-Sintered SiC Fiber Preform
(formed from commercial "Sylramic" Fiber)

→

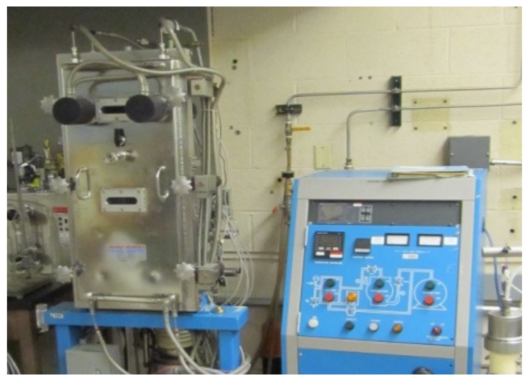
Preform Treatment in High-Pressure N_2
(Boron removal for SOA creep-rupture resistance)

→

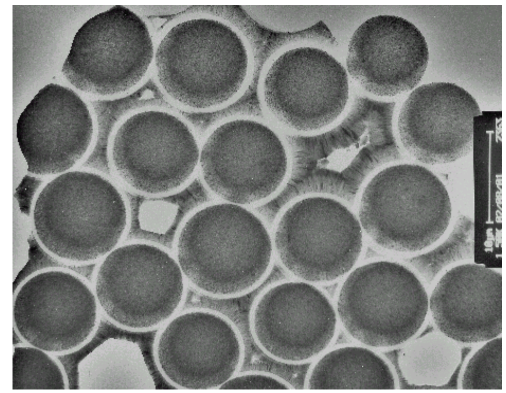
Super Sylramic-iBN Preform
(in-situ grown BN surface layer on each fiber for environmental protection)



Blade Preform



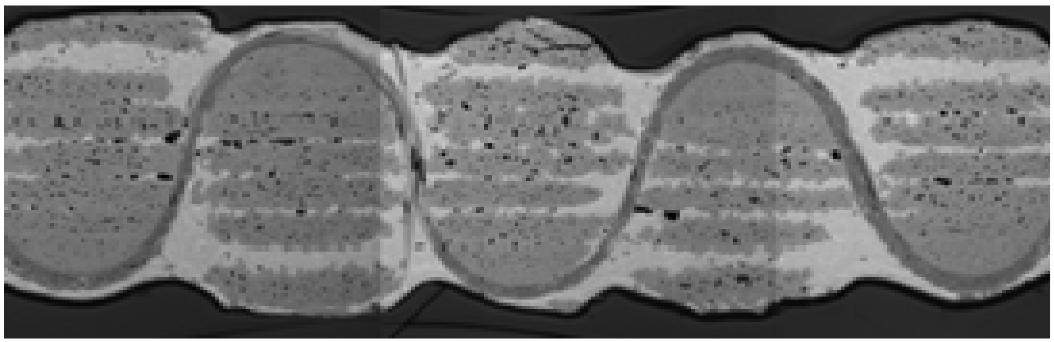
Preform Treatment Furnace



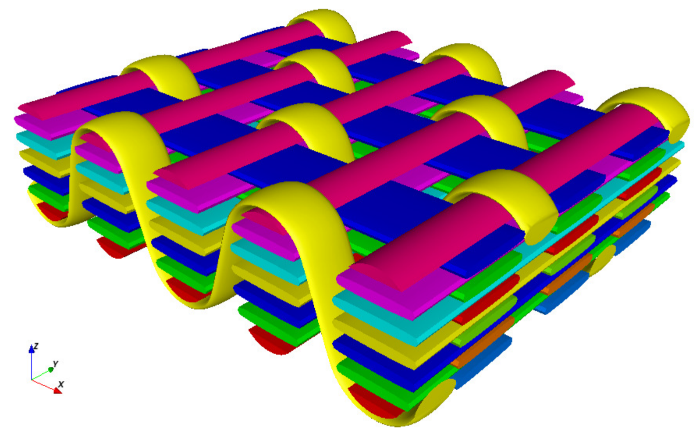
iBN coating
between every fiber

Fiber treatment process improves on 2009 NASA patent for Sylramic-iBN fiber

3D fiber architectures increase CMC durability for turbine applications



3D-orthogonal fiber architecture

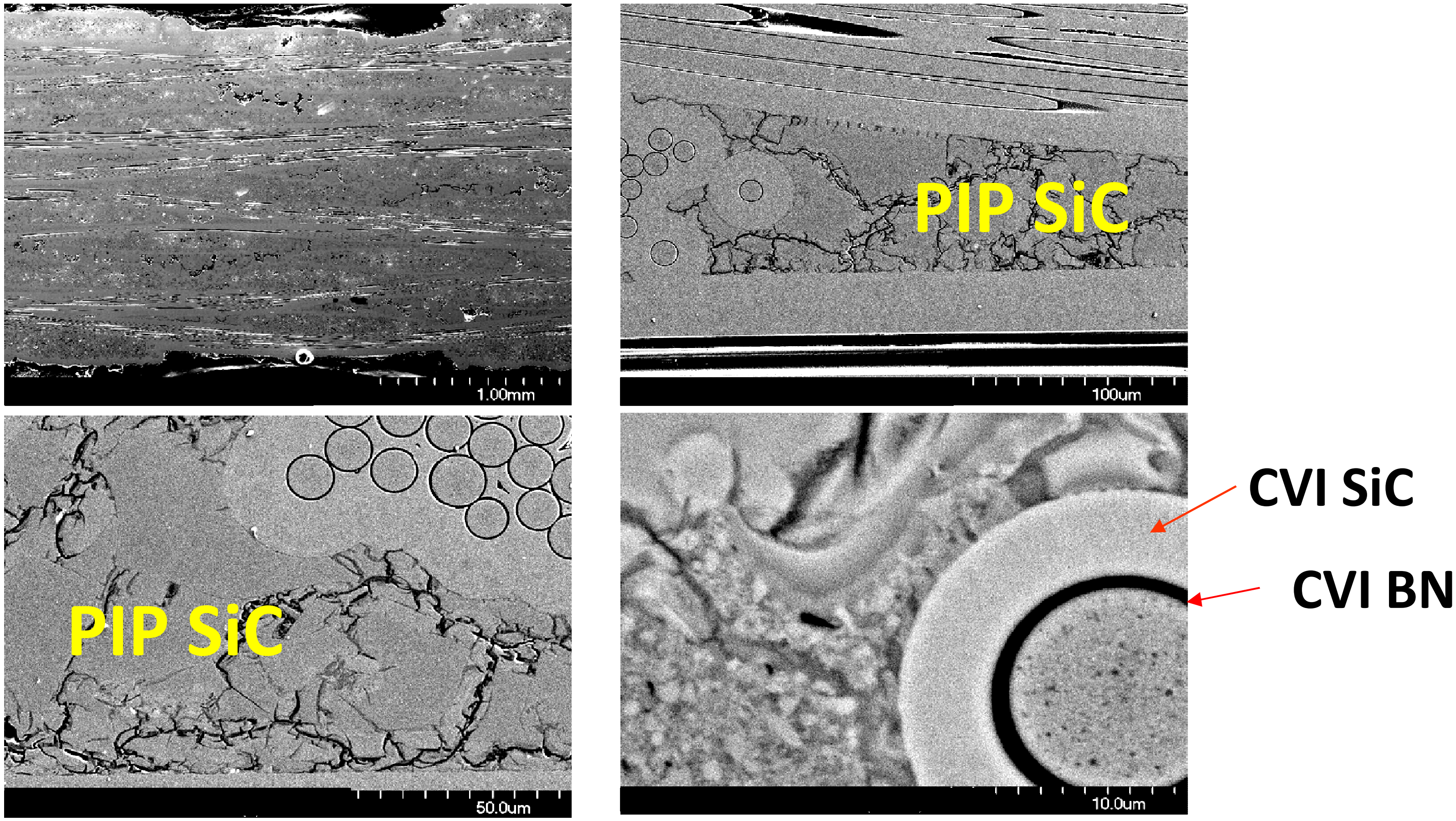


fiber architecture analysis and visualization tool

	Repeating Unit Volume Dimensions, mm			Total Fiber Volume, %		
	H	W	L	Warp Stuffer	Fill Stuffer	Warp Weaver
Predicted	1.9	3.0	1.4	14.3	17.4	3.3
Measured	2.0	3.0	1.4	15.2	17.4	3.2

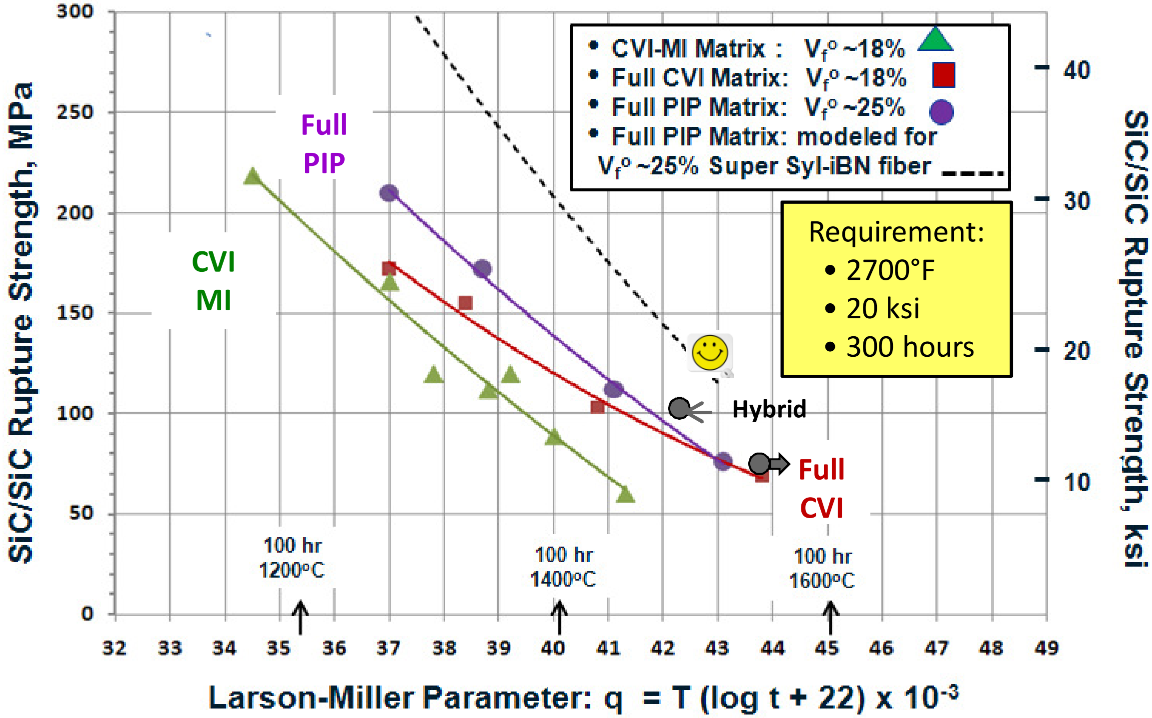
3D fiber architectures suppress delamination and increase thermal conductivity

Hybrid (CVI + PIP) SiC Matrix



- Reduced porosity; higher MCS and thermal conductivity
- Reduced matrix cracking
- Better oxidation resistance & off-axis properties

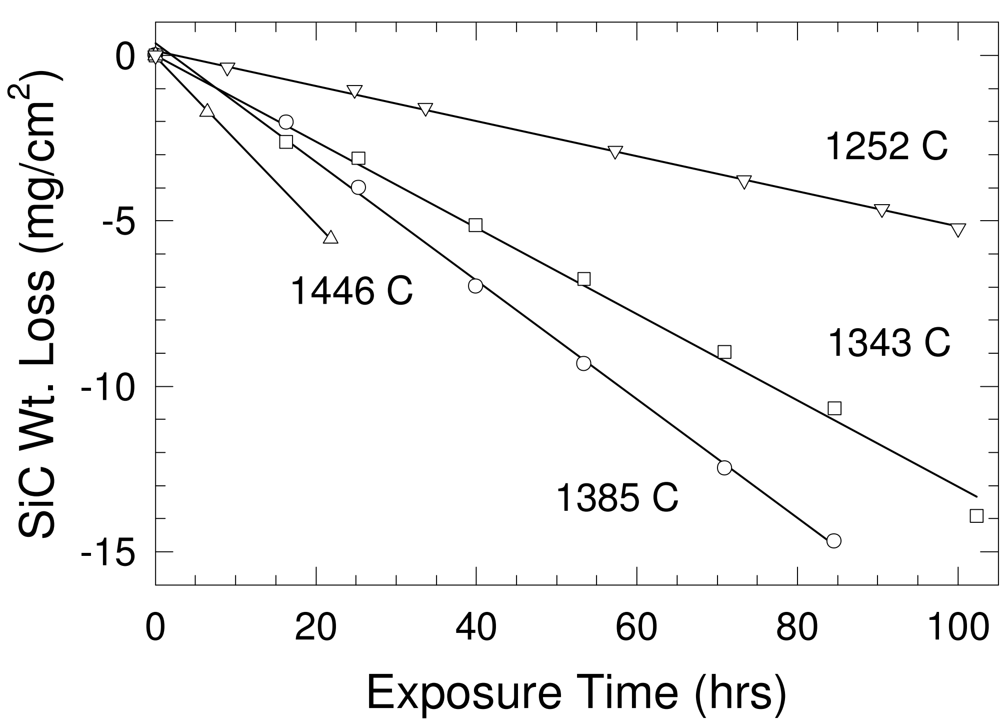
Hybrid Matrix CMC: Durability Comparison



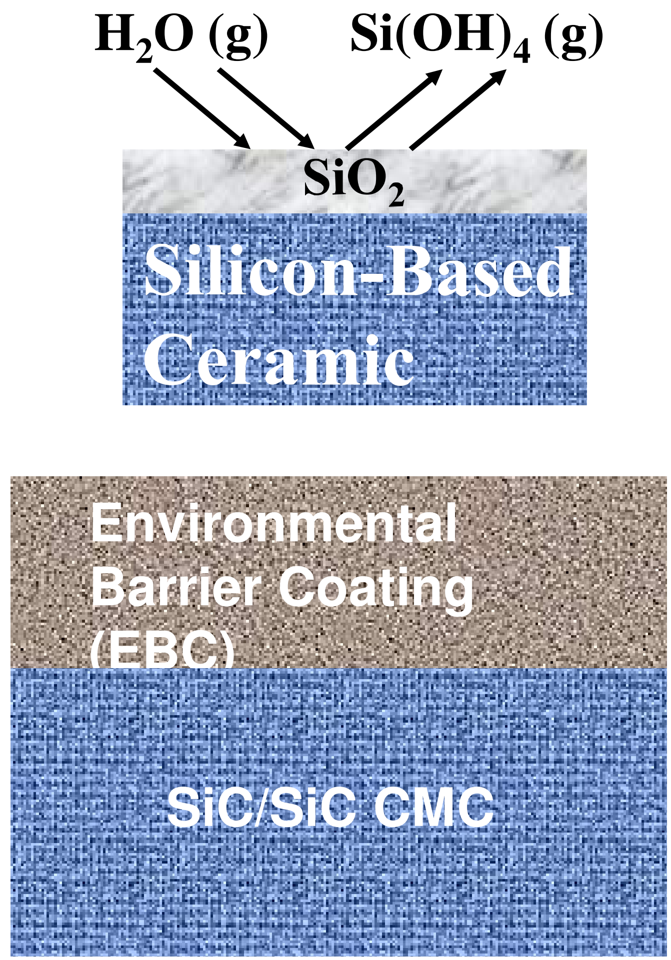
- Hybrid matrix performs better than PIP due to greater creep-resistance of the annealed CVI SiC component
- Hybrid matrix performs better than CVI due to better oxidation resistance of PIP component
- Advanced fiber is needed to meet 2700°F turbine goal

Environmental Barrier Coating is needed for durability of SiC/SiC CMC

Weight Loss of SiC in High Pressure Burner Rig

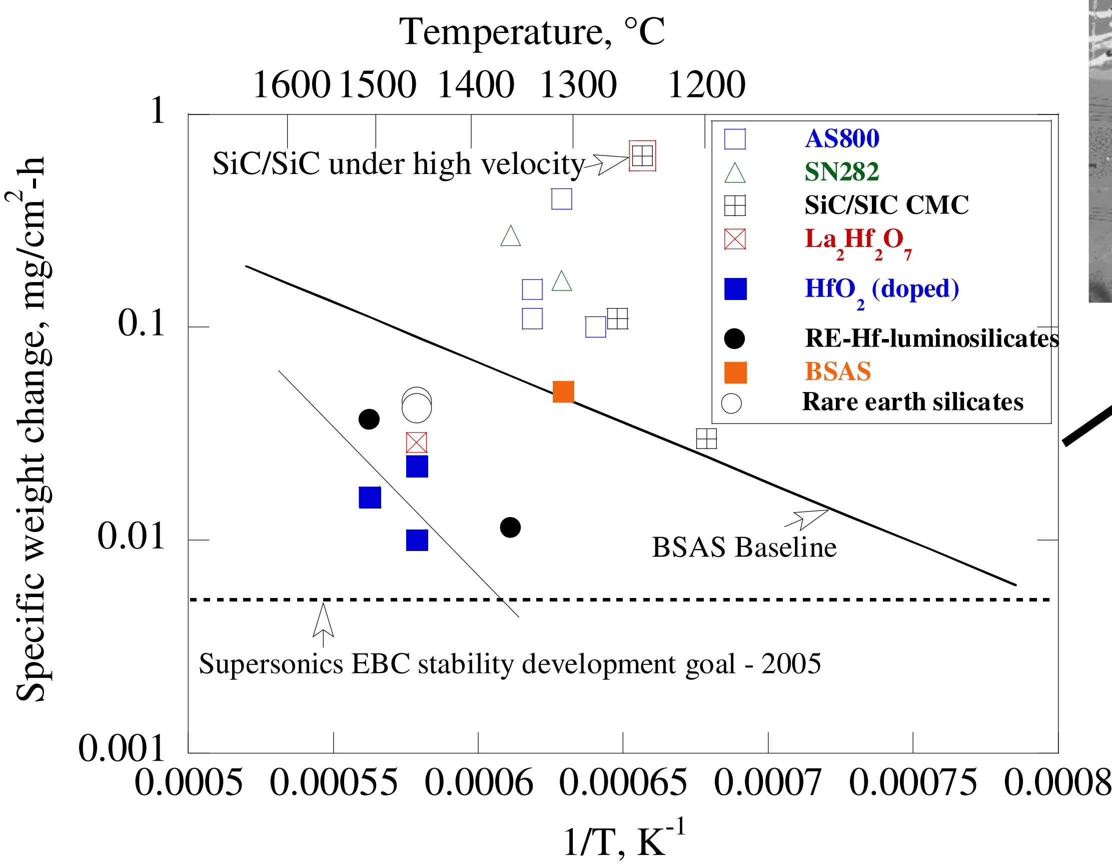


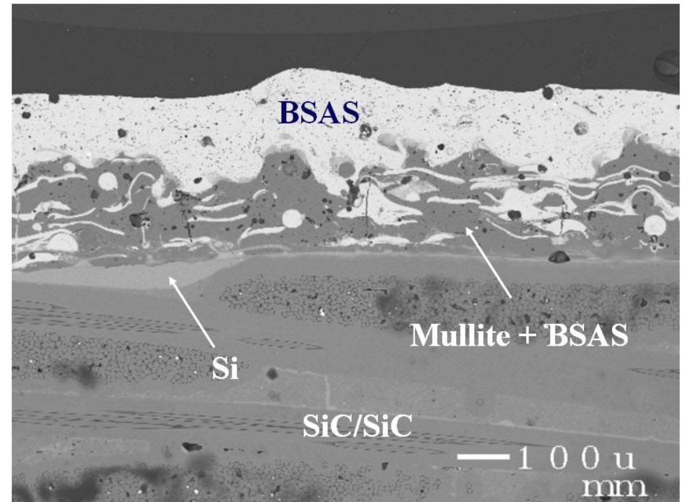
Exposure conditions: 6 atm, 20 m/s airflow



Current State of 2700°F EBC Technology

Weight Change of Candidate EBC Materials in High Pressure Burner Rig Testing





- Weight loss rate too high for “Baseline EBC” BSAS
- Hafnia compounds show better resistance to recession in high pressure burner rig tests

Plasma Spray - Physical Vapor Deposition (PS-PVD) at NASA

GRC facility is second such system in U.S.

- Constructed at NASA GRC in 2008-2010 via contract with Sulzer Metco

Bridges gap between plasma spray and vapor phase methods

- Variable microstructure
- Multilayer coatings
- Thin layers

Low pressure (70-1400 Pa = 0.5 to 10 torr), high power (>100 kW)

- Temperatures up to 10,000K

High deposition rate

- 0.5 m^2 x 10 µm in < 60sec

Spray material incorporated into gas stream

- Non line-of-sight deposition

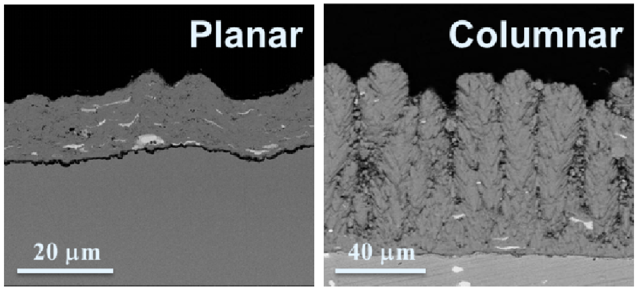
Wide range of applications

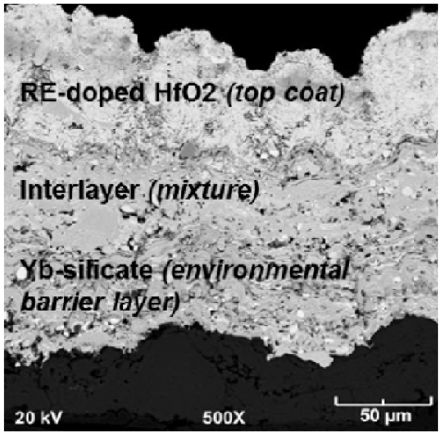
- Various coatings, solid oxide fuel cells, gas sensors, etc.

Plasma during vapor deposition

Exterior of the PS-PVD Rig

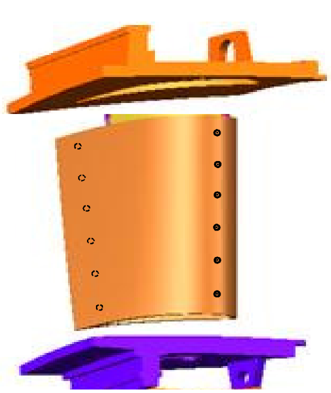
Same material, different processing parameters





PS-PVD Deposited Candidate Coating System for Turbine Engine CMCs

Joining technology for CMC turbine components

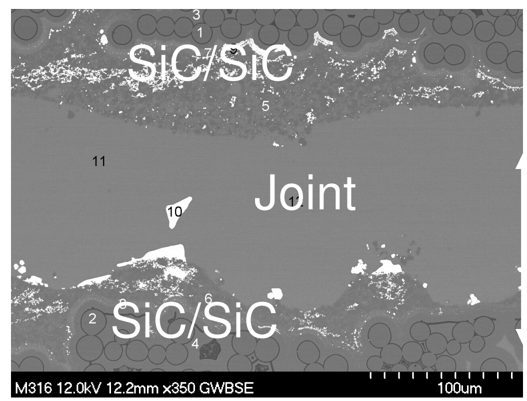


Simplifies fabrication of complex shapes

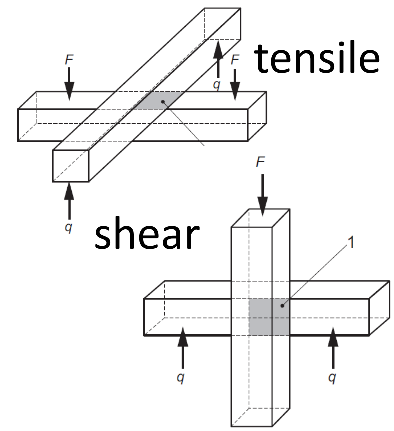
Reduces part count, seals & leakage

APPROACH:

- Develop single, multiple and hybrid interlayer approaches
- Evaluate durability of joints under engine conditions
- Scale-up joining processes for larger & complex components



REABOND technology for crack-free & durable joints



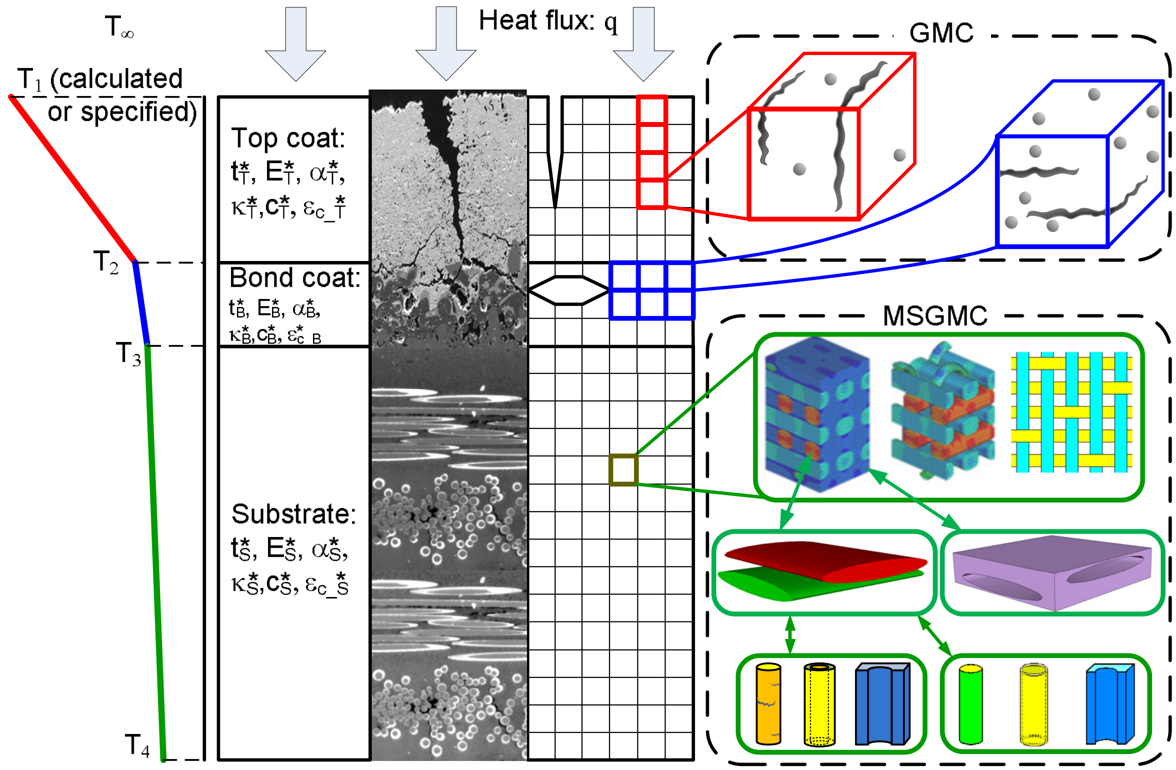
ISO tests for joint strength

Joining capabilities can improve turbine performance

Multiscale Deformation and Life Modeling for CMC Turbine Components

Failure defined as EBC spallation resulting from a combination of:

- EBC cracking
- EBC / bond coat delamination

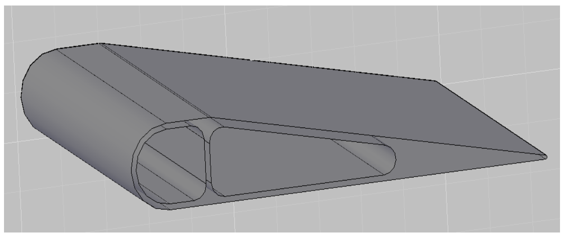


Objective: understand the sensitivity of CMC/EBC failure mechanisms to constituent properties and architectures

Near-Term Development Plans

- 2013: Demonstrate advanced SiC fiber
- 2014: Fabricate and test 2700 ℉ CMC panels & coupons
- 2015: Fabricate turbine subelements and test in a rig environment
  - Compare durability with current SOA CMC materials

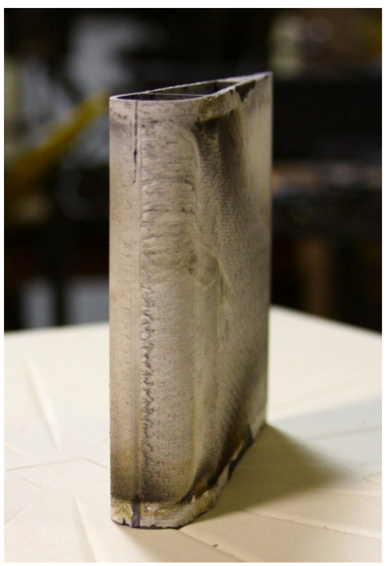
Durability testing of baseline turbine vane subelement in simulated engine environment has been initiated



turbine vane subelement

EBC

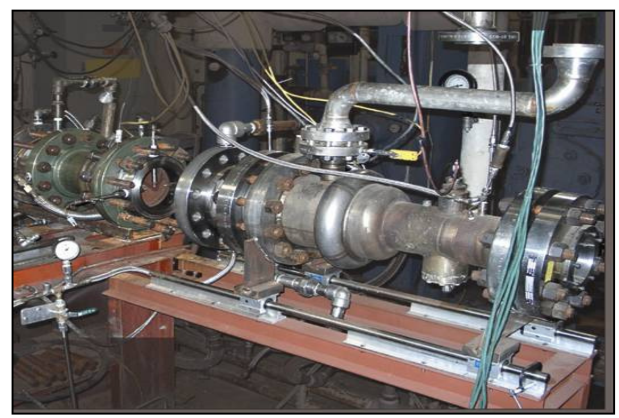
- 5-10 mil thick multilayer coating with hafnia-silicon bond coat and rare earth silicate coatings
- 2700 ℉ temperature capability
- Plasma Spray / PVD application process



1. Prepreg MI SiC/SiC
- *Hi-Nic Type S fibers*
- *BN interface coatings*
- 0/90/0/0/90/0° tapes
- 22% Fiber volume ratio

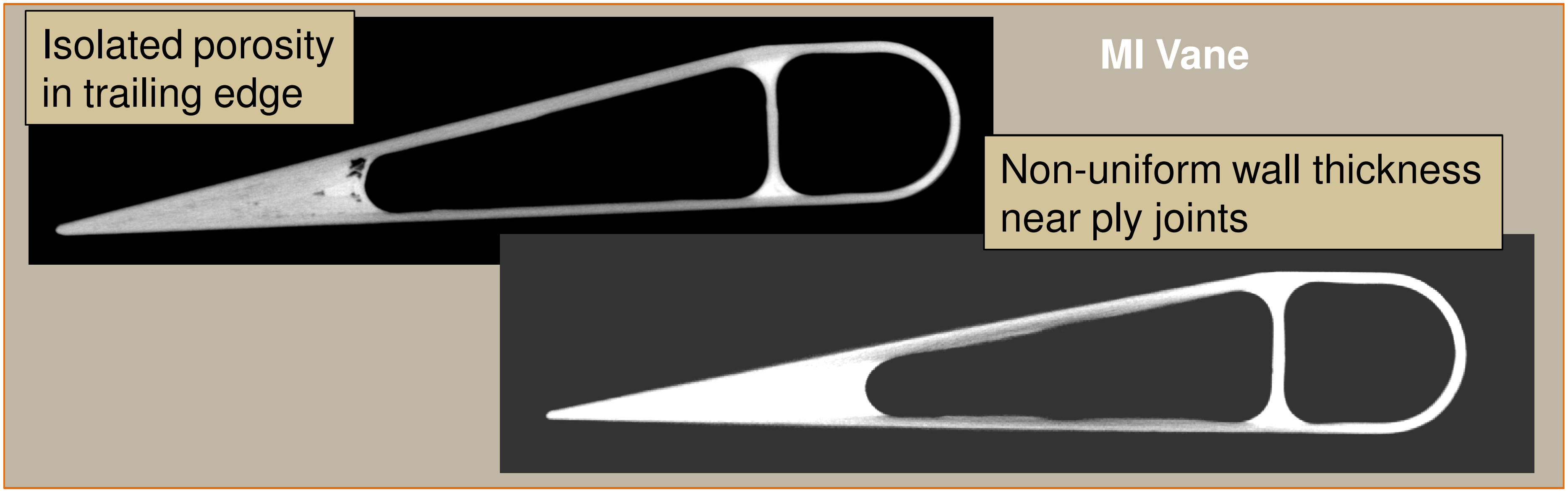
2. CVI SiC/SiC
- *Hi-Nic Type S fibers*
- *BN interface coatings*
- 5 HS weave
- 35% fiber volume ratio

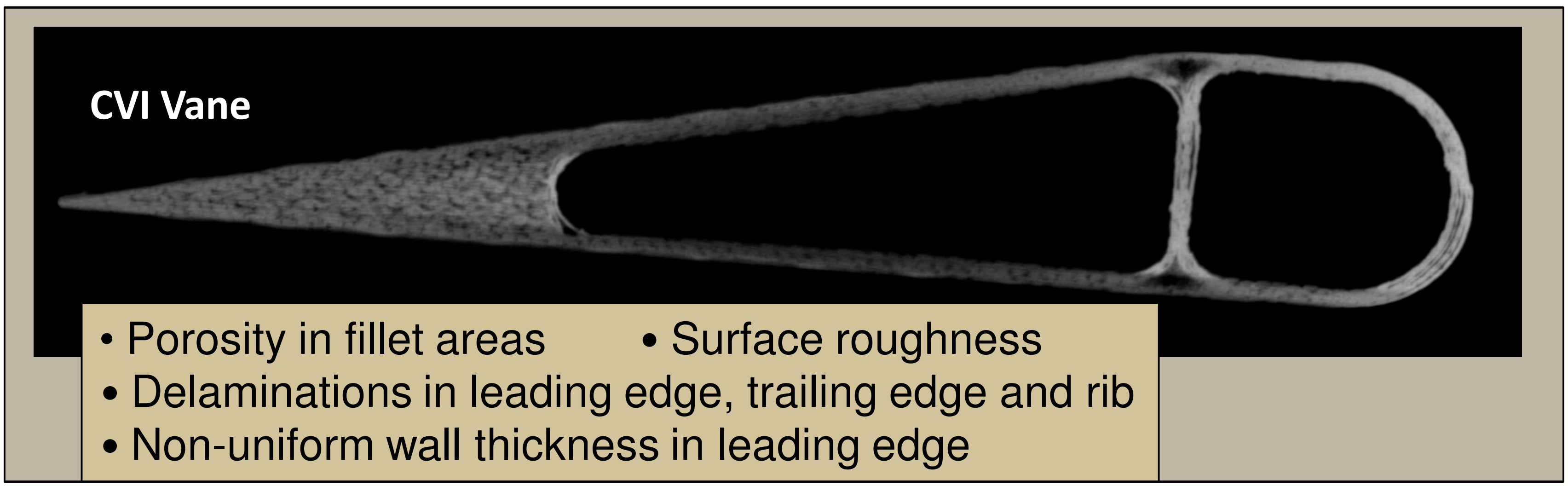
High Pressure Burner Rig simulated turbine operating conditions



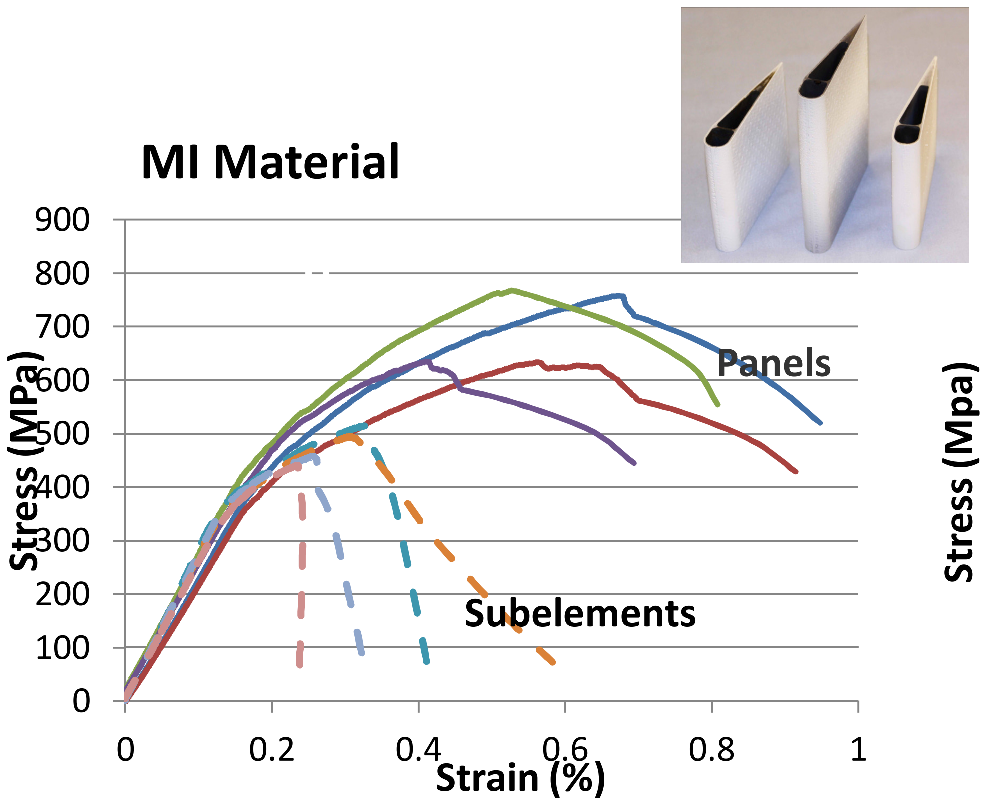
30 hours of testing has been completed at 2500ºF, 10 atmospheres and 200 m/s gas velocity

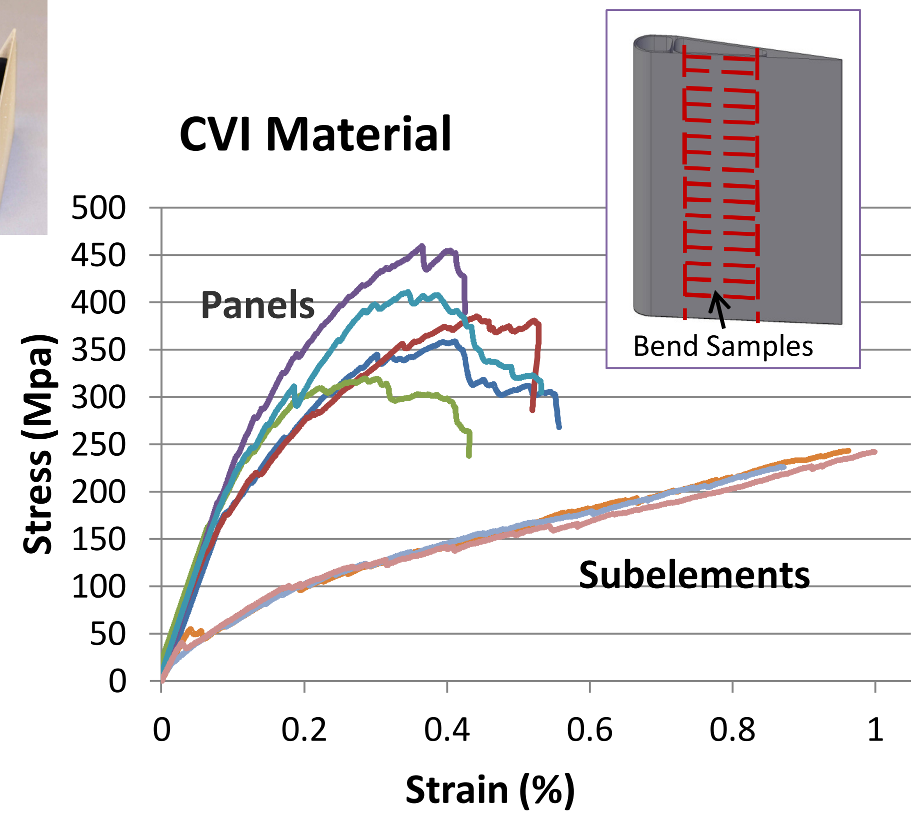
CT scans detect subelement fabrication flaws





Bend tests showed strength and modulus loss in fabricating turbine vane subelements





Porosity after infiltration of complex shape reduced strength, stiffness and thermal conductivity of turbine vane subelements

Summary

- A 2700°F CMC would enable a 6% reduction in engine fuel burn due to the reduced need for turbine cooling

- This requires development of an advanced fiber, fiber architecture, matrix and EBC, and is the basis of NASA's CMC technology development program

- In 2015, NASA will compare durability of an advanced 2700F CMC with current CMC systems in rig tests that simulate an engine environment